

# Very High Resolution Simulation of Compressible Turbulence on the IBM-SP System

**CASC** Center for Applied Scientific Computing



Gordon Bell Award  
for Best Performance

## **Lawrence Livermore National Laboratory**

A.A. Mirin, R.H. Cohen,  
B.C. Curtis, W.P. Dannevik,  
A.M. Dimits, M.A. Duchaineau,  
D.E. Eliason and D.R. Schikore

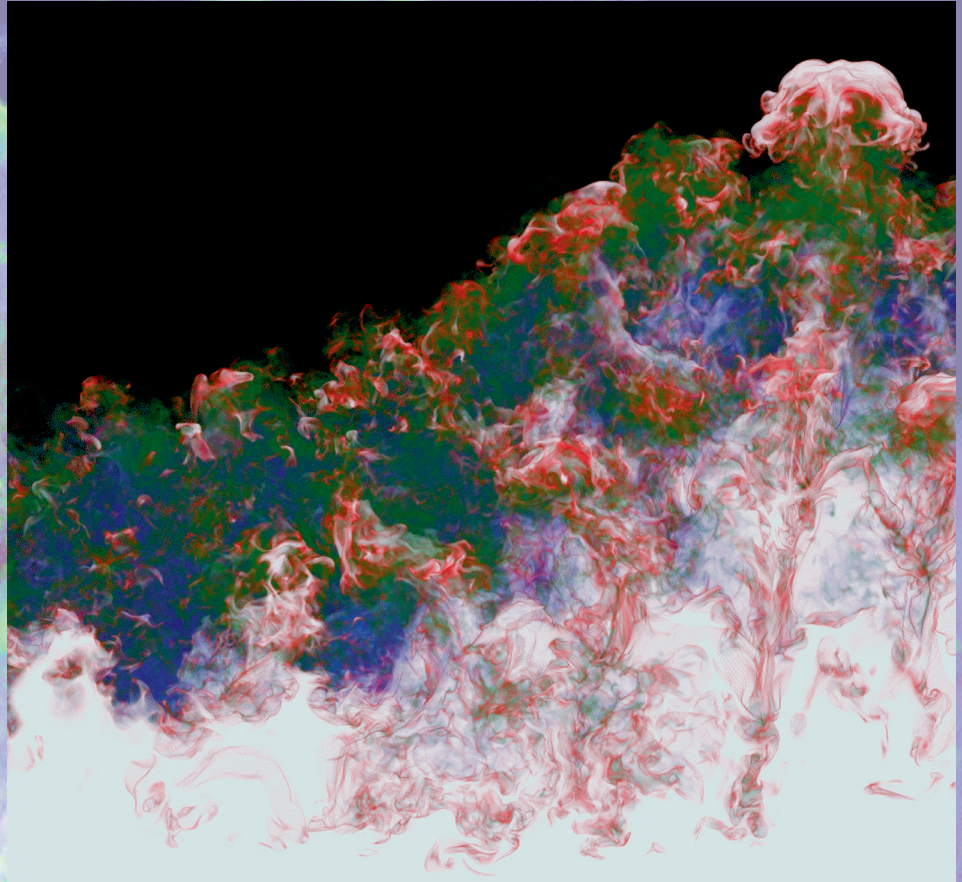
## **University of Minnesota**

S.E. Anderson, D.H. Porter and  
P.R. Woodward

## **IBM**

L.J. Shieh and S.W. White

Understanding turbulence and mix in compressible flows is of fundamental importance to real-world applications such as chemical combustion and supernova evolution. The ability to run in three dimensions and at very high resolution is required for the simulation to accurately represent the interaction of the various length scales, and consequently, the reactivity of the intermixing species. Toward this end, we have carried out a very high resolution (over 8 billion zones) 3D simulation of the Richtmyer-Meshkov instability and turbulent mixing on the IBM Sustained Stewardship TeraOp (SST) system, developed under the auspices of the Department of Energy (DOE) Accelerated Strategic Computing Initiative (ASCI) and located at Lawrence Livermore National Laboratory. We have also undertaken an even higher resolution proof-of-principle calculation (over 24 billion zones) on 5,832 processors of the IBM system, which executed for over an hour at a sustained rate of 1.05 Tflop/s, as well as a short calculation with a modified algorithm that achieved a sustained rate



**Figure 1. Volume rendering of entropy for 8-billion-zone simulation of the Richtmyer-Meshkov instability, showing the coexistence of both fine- and large-scale structures.**

of 1.18 Tflop/s. The full production scientific simulation, using a further modified algorithm, ran for 27,000 timesteps in slightly over a week of wall time using 3,840 processors of the IBM system, clocking a sustained throughput of roughly 0.6 teraflop per second (32-bit arithmetic). Nearly 300,000 graphics files comprising over three terabytes of data were produced and post-processed. The capability of running in 3D at high resolution enabled us to get a more accurate and detailed

picture of the fluid-flow structure – in particular, to simulate the development of fine scale structures from the interactions of long- and short-wavelength phenomena, to elucidate differences between two-dimensional and three-dimensional turbulence, to explore a conjecture regarding the transition from unstable flow to fully developed turbulence with increasing Reynolds number, and to ascertain convergence of the computed solution with respect to mesh resolution.



# Very High Resolution Simulation of Compressible Turbulence on the IBM-SP System

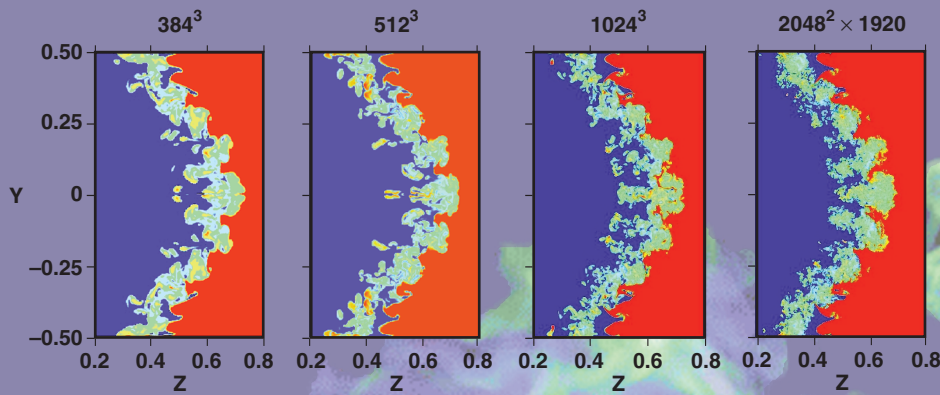


Figure 2. Renderings of entropy along vertical slices suggest transition to turbulence with increasing mesh resolution (hence decreasing numerical dissipation).

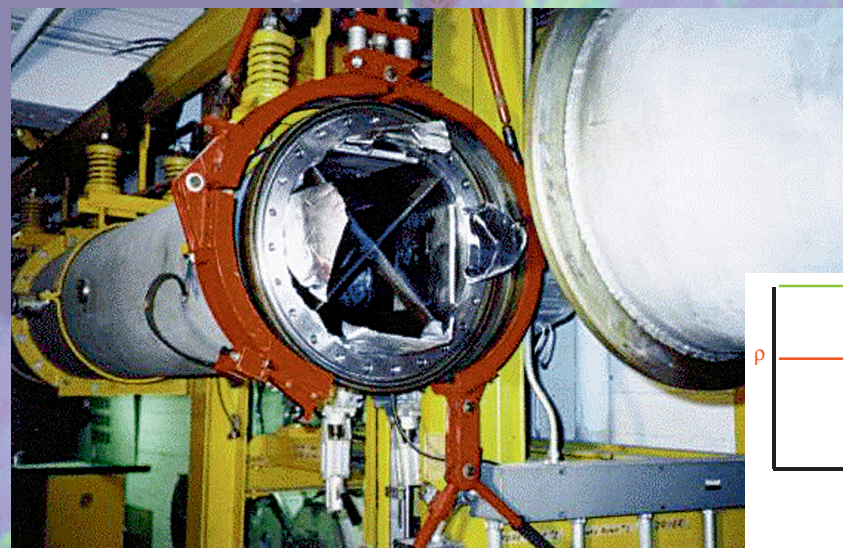


Figure 4. Photo above shows the ruptured membrane of a 17-inch shock tube at Graduate Aeronautical Laboratories, Caltech (GALCIT). The calculation herein is an approximate simulation of that experiment. On the right is a schematic diagram of a shock tube. A shock going from left to right impinges on a contact discontinuity, leading to the Richtmyer–Meshkov instability.

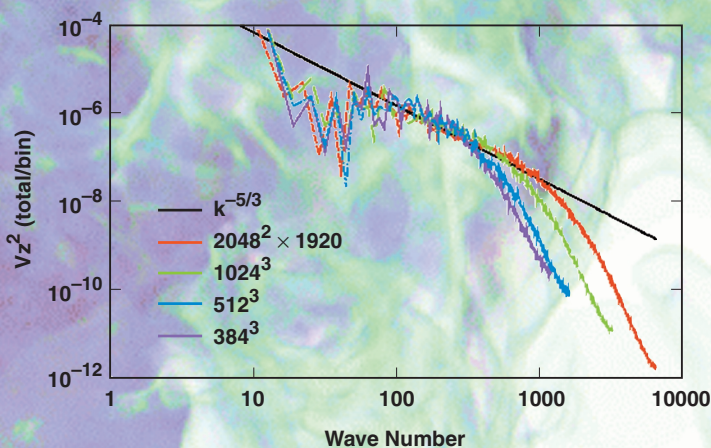


Figure 5. Power spectrum of longitudinal momentum in horizontal slice through mixing layer, versus mesh resolution. The results suggest the formation of an inertial range as the numerical dissipation decreases (mesh resolution increases).

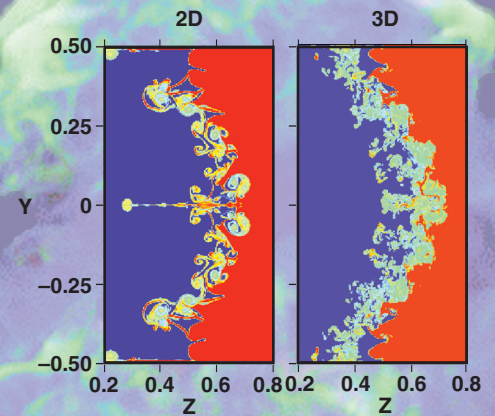


Figure 3. Comparison of 2D and 3D simulations reinforces theoretical prediction that mixing layer structure is fundamentally different in 2D versus 3D.

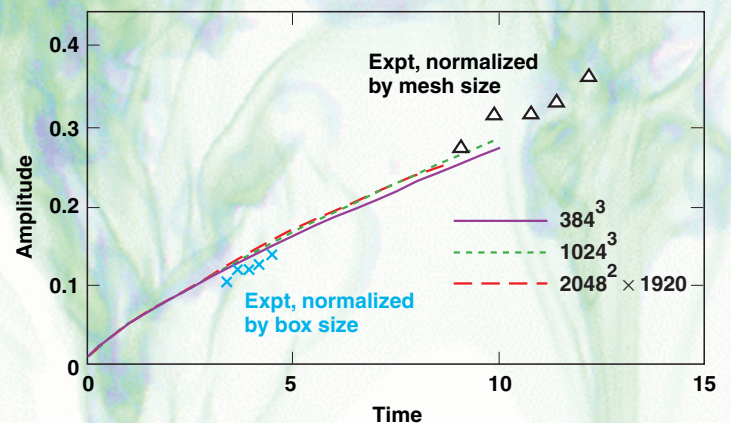
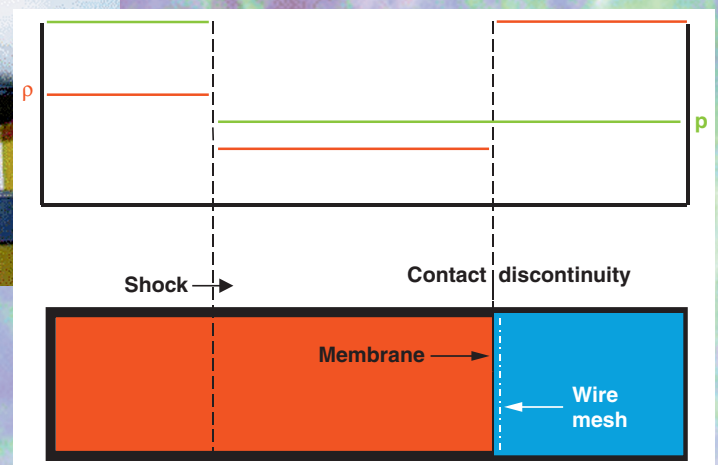


Figure 6. Mixing layer width evolution versus 17-inch shock tube experimental results, for various mesh resolutions. The fact that the simulation used a different ratio of box spacing to wire mesh spacing leads to two possible normalizations.